Central Power Systems

Ensuring Low-Cost Electric Power

Program Areas

- Clean Coal Technology Demonstrations
- Innovations for Existing Plants
- Turbine Systems
- Low-Emissions Boiler System (LEBS)
- Indirect Fired Cycles (IFC)
- Pressurized Fluidized-Bed Combustion (PFBC)
- Gasification Technologies
- Vision 21 Systems

Introduction

The United States has a central electric power generation infrastructure unsurpassed in the world. It is an invaluable asset that affords U.S. industrial customers some of the lowest power rates in the world—37 percent lower than the European average, 49 percent lower than Germany, and 73 percent lower than Japan.

An Invaluable Energy Asset

Existing Plants

A major factor in realizing these low rates is the use of coal, our most abundant energy resource, for more than 50 percent of the generating capacity.

To maintain competitive energy rates and sustain economic growth requires that coal remain a mainstay in electric power generation. This requirement places importance on retaining existing coal-fired capacity and developing new capacity in the face of increased electric power demand and projected nuclear and hydroelectric plant retirements.

However, existing coal-fired plants must comply with increasingly stringent source emission and ambient air standards. For many of these plants, repowering rather than simply modifying the boilers may be necessary to meet environmental standards and remain competitive in a deregulated power market. There is a need to enhance the cost and performance of both environmental control retrofit and repowering technologies aimed at reducing emissions of sulfur dioxide, oxides of nitrogen, fine particulate matter, and mercury.

Installation of an advanced scrubber under the Clean Coal Technology Program enabled Northern Indiana Public Service Company's Bailly Generating Station to be the first to comply with SO_2 standards established in the Clean Air Act Amendments of 1990.

Next Generation Plants

New coal-fired capacity faces even greater challenges, particularly with the implementation of utility restructuring. To maintain ambient air standards, new capacity additions will have to achieve near-zero pollutant emissions. Concerns over global climate change have placed a premium on efficiency and use of carbon-neutral renewable fuels. Solid waste disposal is becoming an increasingly difficult permitting issue. Moreover, under utility restructuring, power generators must shoulder the cost and risk of installing new capacity rather than the consumer. This fact makes the capital intensive, difficult to permit coal-fired plant somewhat less attractive. In addition, uncertainty associated with utility restructuring has impa cted reliability of delivery. Power generators are increasing capacity factors on existing plants rather than adding new capacity, which reduces reserve margins.

A next generation of coal-fired power plants is emerging. These systems offer the potential to be competitive from a cost and performance standpoint with all other power systems. But, they must first undergo replication to reduce cost and optimize performance. This opportunity exists in foreign markets dependent on coal, such as developing Asia, in niche applications placing a premium on performance. This market is significant with nearly half of the 65 percent increase in worldwide energy consumption projected to occur in developing Asia.

Natural gas-based power systems are expected to provide more than 80 percent of the projected 363 gigawatts of new domestic capacity needed to meet new demand and replace plant retirements. The reasons for the move to increased natural gas-based systems include the relatively low capital costs, short permitting and construction time, and superior environmental performance. The concern is the strain such demand might have on natural gas supplies and infrastructure. Strides toward enhancing the efficiency of natural gas-based power systems would serve to protect our reserves of this premium fuel and address global climate change concerns as well.

Vision 21 Plants

Ultimately, to effectively respond to the expanding energy markets and growing regional and global environmental concerns in the 21st century, power systems must incorporate a number of features. Fuel flexibility is critical to enabling use of low-cost indigenous fuels, using wastes to address growing solid waste management problems, and incorporating renewable fuels to reduce greenhouse gas emissions. Highly efficient use of the fuels is important for reducing cost, lowering emissions, and facilitating carbon dioxide capture for sequestration. Product flexibility is needed to enhance efficiency, broaden market applications, and potentially produce vital chemicals or transportation fuels. Near-zero emissions are requisite to environmental acceptability.

The Requirement

Natural gas-based capacity is expected to provide the primary response to new power demands over the next two decades. To ensure conservation of this premium fuel resource requires increasingly efficient natural gas-powered systems.

Coal-fired electric generating capacity is the cornerstone of the nation's central power system. To preserve this foundation requires innovative, low-cost environmental compliance technologies for existing plants and new high-efficiency coal-based systems with near-zero emissions.

Ultimately, a new generation of Vision 21 technologies is needed to expand the fuel resource base to wastes and renewables, provide a multiplicity of high-value products in lieu of wastes, realize quantum jumps in efficiency and emissions reduction, and facilitate CO_2 capture and sequestration.

Program Drivers

- Preserve existing power generation infrastructure at minimal environmental compliance cost.
- Provide next generation power systems to meet near- to mid-term demands domestically and internationally.
- Build toward achieving Vision 21 plants to eliminate environmental concerns associated with fossil fuel use.

The Program

In partnership with its customers and stakeholders, The C&PS Central Power Systems Program seeks to: (1) preserve the existing central power generation infrastructure while meeting environmental requirements at minimal cost; (2) provide a next generation of advanced fossil-fueled power systems capable of meeting projected energy and environmental demands both domestically and internationally; and (3) build toward achieving Vision 21 plants capable of eliminating environmental concerns associated with fossil-fueled power generation.

Existing Plants

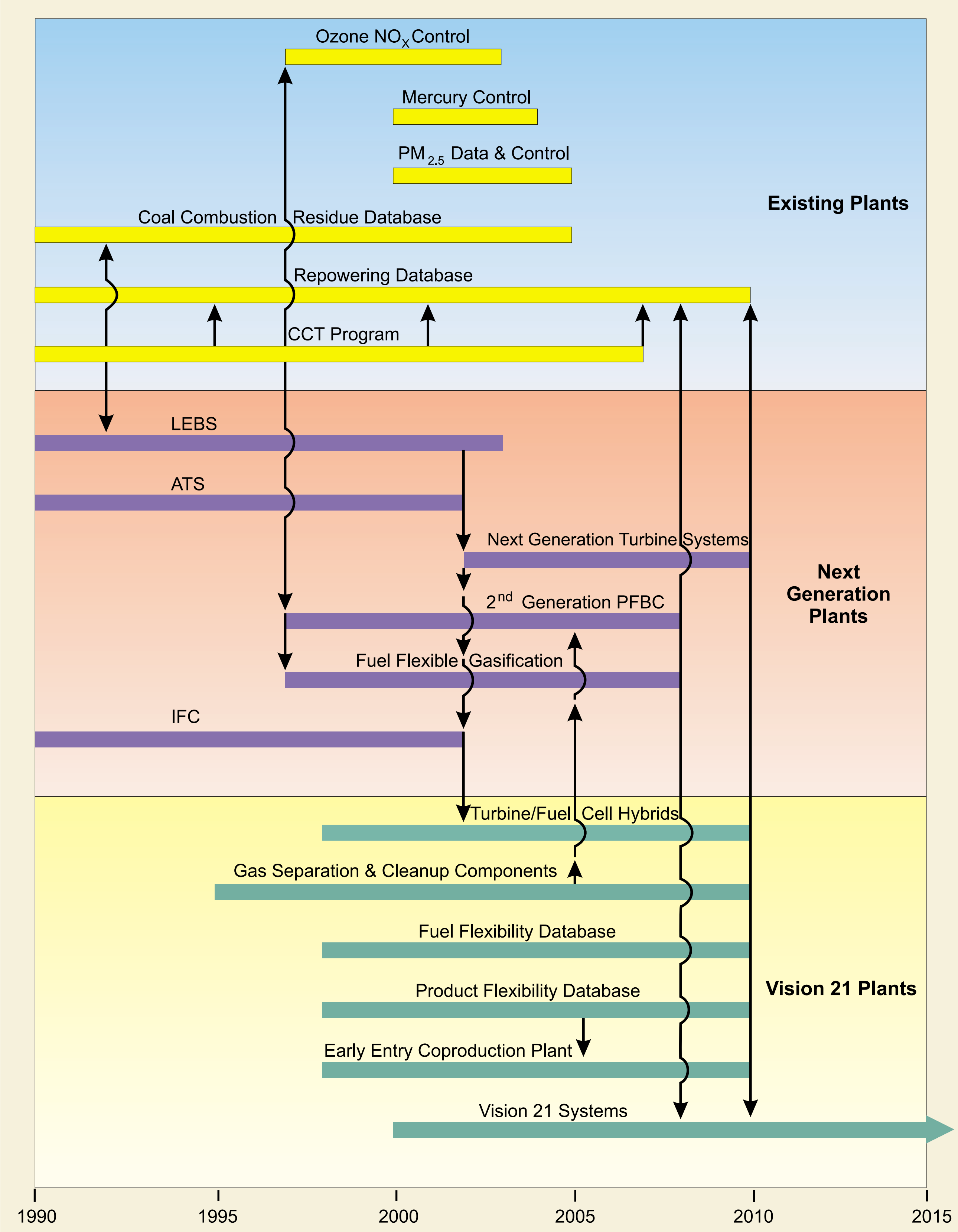
The Program builds on the cost-shared government/industry Clean Coal Technology (CCT) Program projects. These projects enable cost-effective compliance with the Clean Air Act, provide a foundation for meeting more stringent ambient air standards, and represent the first-of-a-kind advanced coal-based electric generation platforms for powering the 21st century. The results of SO_2, NO_x, and combined SO_2/NO_x control projects are available now. The results of all projects will be fully disseminated by 2007.

Drawing upon the CCT projects, cooperative research and development is continuing with state governments and industry to address the ambient NO_x, and $PM_{2.5}$, and vapor phase mercury source emission issues emerging subsequent to the CCT Program. Work is scheduled for completion on NO_x control systems designed to meet the latest ambient air standards associated with ozone levels at costs 25–50 percent below that of current technology. Demonstration of effective control of vapor phase mercury emissions from coal-fired plants is planned for 2004. Data collection and development of control strategies and technologies for respirable particulate matter 2.5 microns or less in size ($PM_{2.5}$) is scheduled for completion by 2005.

Cooperative research and development work with universities and industry is continuing toward characterizing solid residues from existing and advanced power generation systems and developing cost-effective uses for these materials. The results of this work are to be transferred to potential industry users and relevant regulatory agencies by 2005.

A database on coal-fired plant repowering options is being compiled using CCT Program project data, information from the Electric Power Research Institute and Gas Research Institute, cooperative government/industry work, and in-house research. Technologies include boiler augmentation with gas turbines, boiler replacement with advanced power systems, and integration of artificial intelligence controls.

Roadmap


Ozone NOx Control
Mercury Control
PM 2.5 Data & Control
Existing Plants
Coal Combustion Residue Database
Repowering Database
CCT Program
LEBS
ATS
Next Generation Turbine Systems
Next Generation Plants
2nd Generation PFBC
Fuel Flexible Gasification
IFC
Turbine/Fuel Cell Hybrids
Gas Separation & Cleanup Components
Fuel Flexibility Database
Product Flexibility Database
Vision 21 Plants
Early Entry Coproduction Plant
Vision 21 Systems
1990
1995
2000
2005
2010
2015

NEXT GENERATION PLANTS

Under development is a 2nd generation pulverized coal-fired power generation system—the Low Emissions Boiler System (LEBS). The system draws upon the environmental control technologies emerging from the CCT Program and fully integrates the environmental controls in the design. The goal is to demonstrate the capability to reduce cost of electricity by 10 percent and increase efficiency to 42 percent by 2003. LEBS will serve as an early entry, high-efficiency coal-based system for the Asian export market.

To meet the increasing demand for natural gas-based power, an ongoing Advanced Turbine System (ATS) program is scheduled to complete demonstration of two utility-scale gas turbines by 2002. These systems will be capable of achieving 60 percent efficiency on a lower heating value basis (LHV) and NO_x emissions less than 9 parts per million (ppm). The ATS developments will result in new commercial turbine offerings, and these turbines will be used to enhance the efficiency of the pressurized fluidized-bed combustion (PFBC), gasification, and indirect fired cycle (IFC) systems. A Next Generation Turbine System effort will be initiated in 2001, applying ATS lessons-learned to development of more efficient and fuel-flexible intermediate and larger size gas turbines.

Early efforts in the CCT Program resulted in demonstration and commercialization of 1st generation PFBC. PFBC systems apply fluidized-bed combustion in a pressurized atmosphere to generate sufficient flue gas energy to drive a gas turbine and generate steam from the exhaust to drive a steam turbine. This combination termed combined-cycle affords significantly higher efficiency than conventional systems. A 2nd generation PFBC, currently under development, increases efficiency by integrating a coal gasifier (carbonizer) topping combustor to burn the coal derived syngas, hot gas particulate filtration, alkali removal system, Advanced Turbine System, and supercritical steam cycle. The goal is to demonstrate a 52 percent efficient 2nd generation PFBC by 2008. Plans are to have an active CCT Program project to serve as the primary mechanism for the demonstration.

Demonstration of 1st generation PFBC at Ohio Power Company's Tidd Plant resulted in commercialization of the technology.

The CCT Program is currently demonstrating integrated gasification combined-cycle (IGCC) technology. IGCC converts hydrocarbon feedstock into largely gaseous components from which pollutants are extracted and a clean syngas remains for use in a combined-cycle. IGCC demonstrations largely use conventional air separation, pollutant control, and bottom cycle, which either require energy intensive processing or sacrifice efficiency by operating at relatively low temperatures. Next generation gasification technology systems will integrate hot gas particulate filtration, hot gas sulfur/alkali removal, an air separation membrane, and turbine cycle advances to demonstrate a 52 percent efficient system by 2008.

An innovative IFC power system is under development. It uses a high temperature air furnace to separate combustion from an air working media and effectively transfers the heat energy to the air media, which drives an expansion turbine. Two teams are moving the technology toward Vision 21 demonstration.

Vision 21 Plants

An established Advanced Turbine System industry/university consortium and in-house researchers are carrying out cooperative research on low-emissions and low-Btu combustion in support of fuel flexibility and hybrid systems, as well as materials and heat transfer research in support of efficiency enhancement. The intent is to enhance efficiency and develop fuel flexibility for the basic energy platforms such as the ATS, PFBC, gasification technologies, and IFC, as well as the fuel cells and fuel cell/turbine hybrids being developed under the Distributed Generation Program.

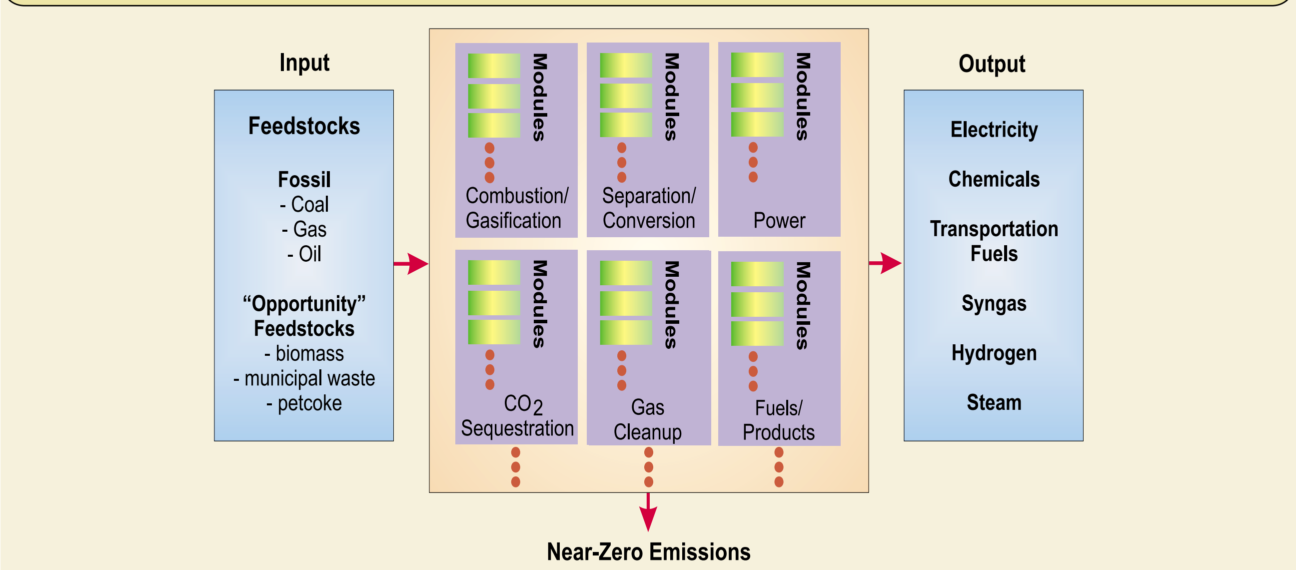
Component research is ongoing in process gas separation and cleanup (essential to improving cost and performance of PFBC, gasification technologies, and IFC systems), and using these energy platforms in hybrid systems capable of significant jumps in efficiency, such as integration with fuel cells. Activities include development of gas separation membranes for air, the development of advanced, low-cost, high-temperature hydrogen separation membranes for gasification technologies/fuel cell applications, and development of advanced gas purification technologies for meeting the more stringent gas quality requirements for fuel cell integration. Gas cleaning and conditioning are essential to meeting rigid syngas quality specifications for fuel cells and catalytic conversion processes used in coproduction of chemicals and fuels.

The contractor-operated Power Systems Development Facility and in-house Gas Processing Development Unit are being used to conduct government/industry cooperative research in fuel and product flexibility, and process gas filtration and cleanup systems.

By 2005, development is to be completed on gas purification and cleanup components essential to 2nd generation PFBC and gasification technologies and an early hybrid system linking coal gasification and a fuel cell. Component development will continue in support of further system cost and performance enhancements and Vision 21 through 2010. Work to enhance fuel and product flexibility will continue through 2010. Product flexibility efforts will feed into development of an Early Entry Coproduction Plant integrating power production and chemical/fuel production, scheduled for completion in 2010. These developments also support both the repowering database for existing plants and Vision 21 systems.

The Vision 21 concept is structured around efforts to successfully demonstrate a portfolio of technology modules. These modules will enable users to optimize system configurations to allow a multiplicity of fuels (gas, coal, biomass, and municipal, forestry, and refinery wastes) and produce a slate of commodities (electricity, steam, chemicals, and clean fuels) with near-zero emissions and thermal efficiencies of 60 percent or more for coal-based systems and 75 percent or more for natural gas-based systems. Advanced computational technology (virtual demonstration techniques) and existing operating systems will be used to minimize the cost of demonstrating Vision 21 systems.

Vision 21 Technology Modules



DRIVERS

- Existing coal-fired electric generating capacity must be retained to sustain economic growth.
- Retaining existing plants requires a portfolio of advanced environmental controls and repowering technologies to meet increasingly stringent emission standards.
- To maintain ambient air standards in most regions of the United States, new capacity additions will have to achieve near-zero pollutant emissions.
- Public policy is placing a premium on efficiency, use of renewable fuels, and elimination of solid waste.
- Natural gas-based power systems are expected to provide more than 80 percent of the 363 gigawatts of projected new domestic capacity by 2020.
- Utility restructuring requires power generators to shoulder the cost and risk of installing new capacity additions.
- Unprecedented worldwide growth in energy consumption is projected—a 65 percent increase by 2020—with coal-dependent Asia accounting for nearly half of the growth.
- Fuel and product flexibility enhances the market potential of power systems by enabling use of low-cost indigenous and opportunity fuels, and production of vital chemicals and transportation fuels.
- Achieving radical improvements in performance of fossil fuel-based power systems and eliminating environmental barriers to fossil fuel use requires integration of power and fuel system "modules" into systems capable of meeting continuing cost and performance challenges.
- Stabilizing global greenhouse gas emissions requires both developed and developing countries to adopt advanced, high-efficiency power technologies.
- Concentrating carbon dioxide emissions from power systems facilitates capture and mitigates sequestration costs.

GOALS

- Disseminate results from the CCT Program. (Present–2007)
- Complete development of retrofit NO_x control technologies necessary to meet the latest ambient air standards associated with ozone levels. (2003)
- Demonstrate technologies to effectively control vapor phase mercury emissions from coal-fired plants. (2004)
- Complete development of data and technology to control respirable particulate matter 2.5 microns or less in size ($PM_{2.5}$). (2005)
- Develop and transfer a database to support environmentally acceptable, cost-effective uses of coal combustion residues. (Present–2005)
- Demonstrate a 60% efficient (LHV) natural gas-based Advanced Turbine System with NO_x emissions less than 9 parts per million (ppm). (2002)
- Complete Next Generation Turbine Systems development. (2010)
- Demonstrate a 42% efficient 2nd generation pulverized coal-fired power generation system—the Low Emissions Boiler System (LEBS). (2003)
- Develop gas purification and particulate cleanup components essential to 2nd generation PFBC and gasification technology goals and for linking early hybrid systems to fuel cells. (2005)
- Demonstrate 52% efficient 2nd generation PFBC and fuel flexible gasification systems capable of near-zero pollutants. (2008)
- Complete development of a hybrid gasification/fuel cell system, fuel and product flexibility databases, and an Early Entry Coproduction Plant integrating power production and chemical/fuel production. (2010)
- Complete design of commercial-scale Vision 21 plants and simulate plants using virtual demonstration capability. (2015)

Strategies

- Build on the cost-shared government/ industry CCT projects.
- Continue cooperative work with states and industry to address current ambient NO_x, $PM_{2.5}$, and vapor phase mercury source emission issues.
- Continue cooperative work with universities and industry to characterize and develop uses for solid residues from existing and advanced power plants.
- Compile database on repowering options using CCT data, information from EPRI and GRI, cooperative government/industry work, and in-house research.
- Integrate ATS developments into new commercial turbine offerings, and use to enhance efficiency of PFBC and gasification technologies.
- Apply ATS lessons-learned and supporting research to develop more efficient and fuel-flexible intermediate size gas turbines.
- Use LEBS as early entry, high-efficiency, coal-based system in Asian export market.
- Use an existing CCT project to demonstrate 2nd generation PFBC.
- Use established ATS industry/university consortium and in-house research to carry out research in fuel flexibility, hybrids, and efficiency enhancement.
- Use Power Systems Development Facility and in-house Gas Processing Development Unit to conduct cooperative research in fuel and product flexibility and process gas separation and cleanup.
- Use a CCT project to demonstrate the Early Entry Coproduction Plant.
- Develop and use advanced computational technology and existing operating systems to demonstrate feasibilty of Vision 21 systems.

Measures of Success

- CCT environmental control and power system technologies realize widespread deployment and significantly reduce regulatory compliance costs.
- Existing U.S. coal-fired capacity is retained and operates at low cost with acceptable environmental performance.
- 1st generation PFBC and IGCC systems emerging from CCT Program realize market entry overseas and begin to bring basic system costs down. (1995)
- Leveraging fuel and product flexibility with PFBC and IGCC results in niche market applications improving cost and performance. (2003)
- ATSs supplant current turbines, reduce pressure on natural gas supply in meeting growing electricity demand, and enhance performance of PFBC and IGCC. (2002)
- Fuel Flexible Gas Turbine Systems emerge and expand market applications. (2010)
- LEBS technology gives U.S. competitive position in overseas markets and results in exports. (2003)
- Success of 1st generation PFBC and IGCC overseas and in U.S. niche markets, and performance enhancements coming out of demonstration of 2nd generation PFBC and fuel-flexible gasification technologies competitively position technologies to enter domestic energy market. (2008)
- IFC technology emerges as high-efficiency combustion module for Vision 21 systems. (2008)
- Gas separation membrane and high-temperature cleanup technology enable hybrid systems to achieve quantum jumps in cost and performance. (2010)
- The Early Entry Coproduction Plant significantly enhances cost and performance of gasification-based systems and increases market penetration.
- Industry participants begin to site Vision 21 plants. (2015)

BENEFITS

CUSTOMER BENEFITS

- Maintains low-cost electricity rates, which are already among the lowest in the world;
- Provides U.S. industrial users a competitive edge for their products in the world marketplace;
- Serves to bolster electric generating capacity reserve margins critical to reliable service;
- Enhances the local, regional, and global environment; and
- Protects against price shocks in industrial chemicals and transportation fuels.

SUPPLIER BENEFITS

- Enables electricity suppliers to cost-effectively adjust to regional energy and environmental demands;
- Broadens the market beyond simply supplying electricity; and
- Allows significant capacity additions at existing sites, which precludes the need for additional plant siting and transmission line installations.

NATIONAL BENEFITS

- Sustains economic growth by maintaining low-cost electricity vital to U.S. industry;
- Ensures energy security by using abundant indigenous resources for a significant component of the energy mix, and by using natural gas resources efficiently;
- Provides alternative means of producing critical chemicals and fuels;
- Responds to regional and global environmental concerns; and
- Establishes a strong U.S. environmental and power generation technology position for export to the world market.

Program Areas

The C&PS Central Power Systems Program focuses on large stationary fossil energy-based power generation technologies with the capability to also use biomass and opportunity fuels such as municipal, agricultural, forestry, and refinery wastes.

Linkages to other DOE offices include C&PS and the Office of Energy Efficiency and Renewable Energy (EERE) sharing responsibility for the ATS Program component. C&PS supports the utility-scale ATS system development, industry/university consortium, materials research for advanced alloys, ATS applications for coal fuels, and the in-house R&D. EERE supports the industrial-scale system development, materials research on thermal coatings, ceramic retrofit engine development, and ATS applications for biomass fuels. EERE's efforts as they relate to C&PS activities are discussed in the Distributed Generation Program Plan.

Together, the portfolio of central power generation systems presented here will enable the nation's consumers to benefit from continued low energy rates, and U.S. industry to remain competitive in the world marketplace and establish a leadership position in key technologies.

Clean Coal Technology Demonstration Program

The Clean Coal Technology Demonstration Program (CCT Program) is a government/industry partnership established to address environmental concerns associated with coal use. The CCT Program represents an investment of over $5.2 billion in advanced coal-based technology, with industry and state governments providing an unprecedented 66 percent of the funding. Of the 38 active CCT projects, there are 29 projects, valued at $3.5 billion, that address central systems applications—18 environmental control projects and 11 advanced electric power generation projects. The other 19 projects involve coal processing for clean fuels and industrial applications, which are addressed in the Fuels section.

All but one of the environmental control projects have completed operation. Three of the 11 advanced electric power generation projects are complete, four are in operation, and the balance are either in design or construction.

The CCT Program has provided a portfolio of NO_x control technologies applicable to all boiler types. These technologies and associated databases have enabled the utility industry to cost-effectively comply with the first wave of NO_x control requirements promulgated to address acid rain concerns, and have positioned the utility industry to respond to emerging standards prompted by ozone concerns. Technologies include: (1) low-NO_x burners and reburning systems that modify the combustion process to limit NO_x formation, (2) selective catalytic and non-catalytic reduction technologies (SCR and SNCR) that act upon and reduce NO_x already formed, and (3) artificial intelligence-based control systems that effectively handle numerous dynamic parameters to optimize operational and environmental performance of boilers.

A portfolio of SO_2 control technologies also resulted from the CCT Program. Technologies are available for the full range of units from old, space-constrained boilers to relatively new large boilers. The two advanced wet flue gas desulfurization projects redefined the state-of-the-art for lime/limestone-based scrubbers by nearly halving capital and operating costs, producing by-products instead of wastes, and mitigating plant efficiency loses.

A demonstration of atmospheric circulating fluidized-bed combustion (ACFB) provided the operating experience and database needed to reduce risk and achieve commercialization for utility-scale systems. Currently, there is an estimated 9.5 gigawatts of commercial ACFB capacity installed worldwide.

Pressurized fluidized-bed combustion (PFBC) technology is achieving market entry as a result of work performed at The Ohio Power Company's Tidd Plant. The CCT demonstration and associated development work have resulted in several commercial sales, including a 360-MWe unit in Japan. The work at Tidd has also provided a foundation for development of a 2nd generation system.

Four integrated gasification combined-cycle (IGCC) projects, representing a diversity of gasifier types and cleanup systems, are pioneering the introduction of this technology by evaluating the systems in commercial service. IGCC is realizing commercial sales, with an estimated 5 gigawatts of installed capacity expected by 2003. The CCT projects are serving to reduce risk for the commercial sales and to provide a foundation for gasification technologies systems development.

Innovations for Existing Plants

The CCT Program has provided a portfolio of environmental control technologies enabling power generators to cost-effectively comply with the Clean Air Act Amendments of 1990 (CAAA) for SO_2, NO_x, and particulate matter. The CAAA set emission standards for SO_2 and NO_x in two phases, with the more stringent standards coming into effect in 2000. Air toxics emissions were also addressed in the CAAA, with 189 organic and inorganic species identified. A comprehensive DOE/EPA/industry cooperative program was initiated through the CCT Program to evaluate air toxics emissions from a cross section of coal-fired plants. The results helped to establish further technology enhancements and focus follow-up efforts to be implemented through the R&D program.

Subsequent to the CAAA, action was taken to tighten ambient air quality standards for ozone and particulate matter. The ozone standards in turn impacted NO_x emissions because NO_x is a precursor to ozone formation. The new particulate matter standards focus on the very fine particulate matter in the respirable range of 2.5 microns or less ($PM_{2.5}$), whereas the CAAA addressed particulate matter in the range of 10 microns or less (PM_{10}). These actions require technology improvements in both NO_x and particulate matter control, and possibly SO_2, as SO_2 forms sulfate particles upon leaving the stack.

Dealing with the solid by-products of combustion and associated environmental controls represents a growing problem because of their sheer volume and dwindling landfill space. Combustion by-products have the potential for many uses, of which potential customers must be made aware.

NO_x Control

The NO_x control work being undertaken entails leveraging CCT Program developments and databases in the areas of low-NO_x burners, selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), and coal and gas reburning. Technology improvements and validations are being carried out through collaborative projects with industry. One such project involves evaluation of an SNCR system on a 640-megawatt (MW) unit at American Electric Power's Cardinal Plant, with participation by a utility consortium and the Electric Power Research Institute (EPRI).

$PM_{2.5}$ Control

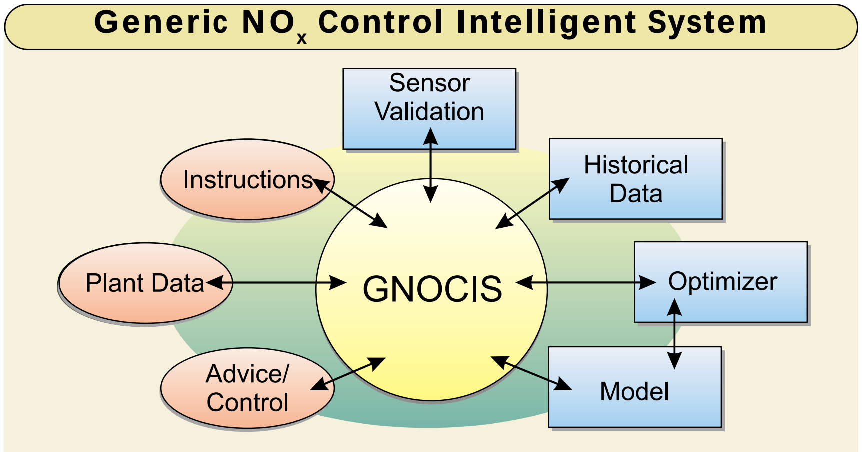
Particulate matter efforts include: (1) data collection to establish characteristics and levels of $PM_{2.5}$ in representative ambient air samples; (2) data collection to understand the formation, transport, and chemical composition of coal-fired fine particulate matter; (3) evaluations to determine the impact of coal-fired systems on air quality; and (4) development of improvements in $PM_{2.5}$ control, leveraging CCT Program technologies and conducting testing in partnership with industry. C&PS is collaborating with EPA, EPRI, and the utility industry in the operation of several ambient air monitoring sites through the Upper Ohio River Valley Project. In this project, four monitoring sites around Pittsburgh, Pennsylvania are enabling comparison of ambient $PM_{2.5}$ in rural and urban settings and providing an understanding of pollutant transport. C&PS is also participating in ambient $PM_{2.5}$ monitoring and characterization studies with the Tennessee Valley Authority in Great Smoky Mountain National Park and with Southern Company Services in the Atlanta, Georgia area.

Air Toxics Control

Air toxics research focuses on control of vapor phase mercury. Approaches include: (1) injecting sorbents upstream of electrostatic precipitator and fabric filter particulate controls; (2) augmenting SO_2 scrubbers; and (3) developing stand-alone controls. Under the Advanced Emissions-Control Development Project, activities are

In DOE's Upper Ohio River Valley Project, an air sampler verifies that $PM_{2.5}$ standards are met, and collects representative samples for detailed information on the chemical composition of fine particulate matter in outdoor air (Greene County, Pennsylvania).

focused on maximizing use of existing controls. Alternately, the Carbon-Based Sorbent Injection for Mercury Control Project is evaluating the mercury-capture effectiveness of various carbon-based sorbents under a joint effort by C&PS, EPRI, and the Public Service Company of Colorado.



Advanced Control Systems

Advanced computer-based controls are an essential component to the increasingly sophisticated environmental control systems being applied today. Optimizing boiler operating and emissions performance requires embedding artificial intelligence (AI) or other advanced computer-based controls into a power plant's digital control system. This need arises from the large number of parameters involved and their dynamic interrelationships. A CCT project at Georgia Power Company's 500-MWe Plant Hammond demonstrated the importance and potential of AI systems. The Generic NO_x Control Intelligent System (GNOCIS™) AI system was installed at Plant Hammond and the plant subsequently achieved an efficiency improvement of 0.5 percent, a reduction in fly ash unburned carbon of 3 percent, and a NO_x reduction of 15 percent. GNOCIS™ is the result of a joint development effort by C&PS, EPRI, PowerGen, Radian International, Southern Company, and the U.K. Department of Trade and Industry. An estimated 35 plants, representing approximately 20,000 MWe of capacity, have either installed or are in the process of installing GNOCIS™.

Combustion By-Products Utilization

An ongoing coal-combustion by-products (CCB) utilization program is addressing the solids residue streams from existing and advanced power generation systems and associated environmental controls. Under the program, solids are characterized, large volume applications identified, necessary equipment developed, and demonstrations conducted. The results are transferred to state and federal regulators and potential users to facilitate application. Applications demonstrated include: (1) injection of large volumes of flue gas desulfurization material and fly ash into underground mine openings to reduce surface subsidence and mitigate acid mine drainage; and (2) use as aggregate for road construction, soil stabilization, and other construction applications. C&PS supports a CCB consortium, managed by West Virginia University. The consortium is chartered to form partnerships with power generators, federal and state agencies, universities, and special interest groups for the purpose of carrying out research, development and demonstration to expand usage options for CCBs.

Repowering

Another environmental compliance option is repowering an existing facility rather than simply adding environmental controls. This is particularly attractive for older plants and plants facing increasing power demands. Repowering integrates new power generating systems, while using much of the existing equipment, and typically increases capacity. This approach leverages the intrinsic value of existing sites, which are already permitted and have established infrastructure such as power line and fuel access. A relatively simple repowering option is to integrate a gas turbine with an existing boiler, using the exhaust to either heat feedwater or replace the primary air. Such approaches can increase capacity by 25–30 percent and efficiency by 5–15 percent. More sophisticated repowering options with greater pay-off in efficiency and capacity increases include PFBC, IGCC, and HIPPS power systems. Gas turbine and power systems developments applicable to repowering and new plant installations are discussed in the following sections. The results of these developments and other related studies are captured and incorporated into a database residing at the NETL.

Turbine Systems: Advanced Turbine System

Performance Targets

Size: Utility-Scale

Efficiency: >60% LHV

NO_x Emissions: <9 ppm

Cost of Electricity: 10% reduction

Year: 2002

A gas turbine produces a high-temperature, high-pressure gas working fluid, through combustion, to induce shaft rotation by impingement of the gas upon a series of specially designed blades. The shaft rotation drives an electric generator and a compressor for the air used by the gas turbine. Many turbines also use a heat exchanger called a recuperator to impart turbine exhaust heat into the combustor's air/fuel mixture.

The gas turbine, once used solely in aviation applications, has evolved into a workhorse in industry and has become the premier electric generation system for peak and intermediate loads. Gas turbines are compact, lightweight, easy to operate, and come in sizes ranging from several hundred kilowatts to hundreds of megawatts.

The Advanced Turbine System (ATS) effort, in support of central power systems, is seeking to enhance the efficiency and environmental performance of utility-scale gas turbines. The utility-scale ATS objectives for operation on natural gas are to achieve 60 percent efficiency or more in a combined-cycle mode, NO_x emission levels less than 9 ppm, and a 10 percent reduction in the cost of electricity.

To achieve the efficiency objective requires significantly higher turbine inlet temperatures. These higher temperatures in turn require advancements in materials, cooling systems, and low-NO_x combustion techniques.

The utility-scale ATS program is being carried out along two parallel paths: (1) major systems development; and (2) technology base development, which supports ongoing and future major systems development. General Electric and Siemens-Westinghouse, world renowned turbine manufacturers, are conducting the major systems development work. Each is developing their own concept under separate cost-shared cooperative agreements with DOE. Both companies have completed component and subsystem testing. Completion of prototype system testing to evaluate combustion, heat transfer, and aerodynamic design under actual operating conditions is scheduled for 2001. Commercial units are scheduled for market entry in 2002 to meet increasing demands for natural gas-based power.

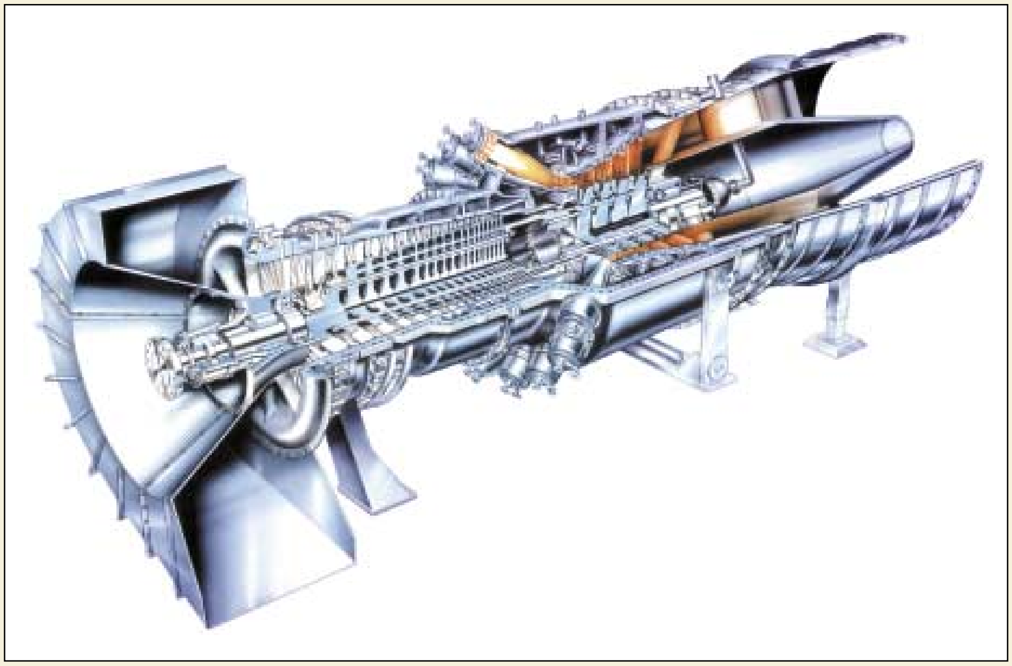
The focus of General Electric's effort is an "H" series gas turbine. To accommodate elevated turbine inlet temperatures, General Electric is employing a novel steam cooling system and newly developed single-crystal turbine blades. Development of the single-crystal casting technique for large complex components represents a breakthrough in manufacturing methods. Single-crystal materials are stronger than polycrystalline materials and provide superior resistance to high-temperature corrosive conditions.

Siemens-Westinghouse is using its 501G turbine as a test bed for the ATS design. Computer modeling has allowed design refinements contributing to capital cost reduction and efficiency enhancement. These include a piloted ring combustor, which uses a lean, premixed multi-stage design to produce ultra-low pollutant emissions and stable turbine operation. Siemens-Westinghouse has also developed brush and abradable coating seals to reduce internal leakage and thermal barrier coatings for turbine blades to permit higher temperatures. These developments have already been incorporated into the commercial 501G turbine.

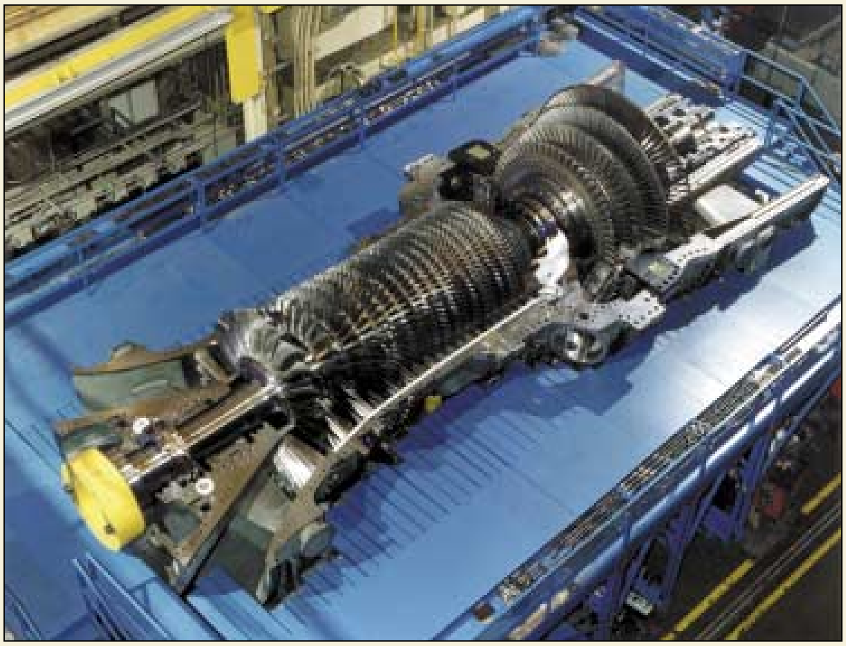
The technology base development effort includes both the advancements in materials, cooling, instrumentation, and control and combustion techniques needed for operation at elevated temperatures; as well as specific studies in support of component and systems development in areas such as heat transfer and aerodynamics. The work is carried out through in-house research at NETL and an industry/university consortium established under the ATS Program.

NETL conducts collaborative research with universities and industry in low-emissions and low-Btu combustion at highly instrumented, established facilities. The low-emissions activities supports ATS NO_x emission reduction goals. The low-Btu combustion work supports expanding the fuel flexibility of gas turbines by developing the capability to operate on gases derived from gasification of coal, biomass, and wastes. The in-house work also involves the development of the associated instrumentation and controls. An example of a specific NETL activity is its partnership with United Technology Research Center. The work entails identifying and modeling combustor configurations to efficiently burn high-moisture, high-pressure gas/air mixtures. This humid air turbine (HAT) concept has the potential for very low emissions and enhanced power and efficiency.

The industry/university consortium supports applied research for 95 U.S. universities, including workshops and student internships at industry facilities. Under the direction of the South Carolina Energy and Research Development Center, contracted universities perform applied research specific to the needs of the ATS developers in combustion, aerodynamics, materials, and heat transfer.



Siemens-Westinghouse's utility-scale advanced turbine



General Electric's utility-scale advanced turbine

Turbine Systems: Next Generation Turbine Systems

Performance Targets

Size: >30 MW

Efficiency: 15%>existing

NO_x/CO Emissions: <5 ppm

Cost: 15% reduction (capital/O&M)

Fuels: Gas and liquids

Operation: Variable

Year: 2010

A follow-on program to the ATS is called the Next Generation Turbine Systems (NGTS) Program. The NGTS goals are to:

- Develop Next Generation Gas Turbine Systems in sizes and duty cycles that will provide public benefits and fill market needs not covered by the ATS Program.
- Target natural gas but provide options to use renewable energy and coal-derived fuels.
- Address both greenfield and repowering applications
- Provide power generation modules as building blocks for Vision 21 plants.

NGTS will provide significant public benefits through increased reliability, superior performance, reduced costs, and near- and long-term reductions of CO_2, NO_x, and other emissions. Because NGTS will be fuel flexible, they will expand the options for high-efficiency conversion of domestic fuels into electric power.

In the near term, NGTS will be suitable for new capacity, repowering of older fossil units, combined heat and power applications, and as efficiency enhancement units for existing fossil-fueled steam plants. In the long-term, NGTS will be adapted and integrated into Vision 21 fossil-fueled plants.

Enabling technologies developed under the program may benefit and support other missions of the U.S. Government, such as enhancing defense capability and serving the needs of future generation military operations. Another large benefit of the NGTS Program is the creation and maintenance of U.S. jobs directly related to the manufacture of turbine systems and those indirectly created and maintained because of the low-cost, environmentally superior performance that will result, and help keep U.S. businesses competitive.

The NGTS Program includes three elements:

1. Systems Development. The Flexible Gas Turbine System (FGTS) is the major thrust of the systems development activity. DOE envisions that most of the R&D will be done by gas turbine developers and vendors of gas turbine system components. FGTS will:

- Be greater than 30 MW in size range;
- Be optimally designed for intermediate and peaking duty, i.e., have high turndown ratios, high part-load efficiency, flexibility of 400 starts per year, and be capable of running in base load operation;
- Have a 15% improvement in net system efficiency over current systems;
- Reduce NO_x and CO emissions to less than 5 ppm to ensure permitting in the post-2008 time frame;

- Have low life-cycle costs, a requirement of the deregulated market (a 15% reduction in operation and maintenance costs and a 15% reduction in capital costs compared to current systems);
- Be able to use multiple fuels (gas and liquid);
- Where applicable, be developed in cooperation with DOD for dual use in civilian and military (propulsion, ship service, and weapon systems) applications; and
- Where applicable, enabling technology or systems components will contribute to the long-term goals of the Vision 21 program. FGTS systems may ultimately be enhanced for applications as Vision 21 power modules.

2. Supporting R&D and Enabling Technology. This R&D will broadly support all gas turbine development and operation. It will be conducted by universities, industry, academia, and research institutes. Technology development needs include:

- High temperature materials and coatings;
- Integration of aircraft turbine-based technology into industrial turbine designs;
- Robust combustion systems;
- Improved computational methods;
- Advanced cooling schemes; and
- Technology for advanced system operation and life cycle cost reduction.

3. Vision 21 Applications and Integration. This element focuses on very high-efficiency hybrid turbine/fuel cell systems and advanced cycles for central station and other large power plants. The goal is to achieve systems with 75% (LHV) efficiencies on natural gas fuels and 60% HHV efficiencies on coal fuels. C&PS will conduct hybrid turbine/fuel cell activities in collaboration with EERE's industrial power program and with C&PS' Fuel Cell and Vision 21 programs. R&D performed under this element will contribute to the enhancement of ATS, FGTS, or other advanced systems to achieve Vision 21 performance and cost goals.

NETL supports hybrid system development in its Low-Btu Combustion Studies Facility. Fuel cell anode gases can be simulated for combustor design studies. The fully instrumented facility is made available for cooperative research between NETL and industry under Cooperative Research and Development Agreements (CRADAs), which are designed to protect industrial participants' intellectual property.

NETL Low-Btu Combustion Studies Facility

Low-Emissions Boiler System

Performance Targets

Efficiency: 42% HHV

Emissions:
NO_x – 0.1lb/10^6 Btu
SO_2 – 0.1lb/10^6 Btu
PM – 0.01lb/10^6 Btu

Year: 2003

The Low-Emissions Boiler System (LEBS) is a 2^{nd} generation pulverized-coal-fired power system. LEBS uses the knowledge gained through the CCT Program and parallel research in pursuit of advanced environmental controls, and applies the knowledge in the design of a new system that leverages effective control mechanisms.

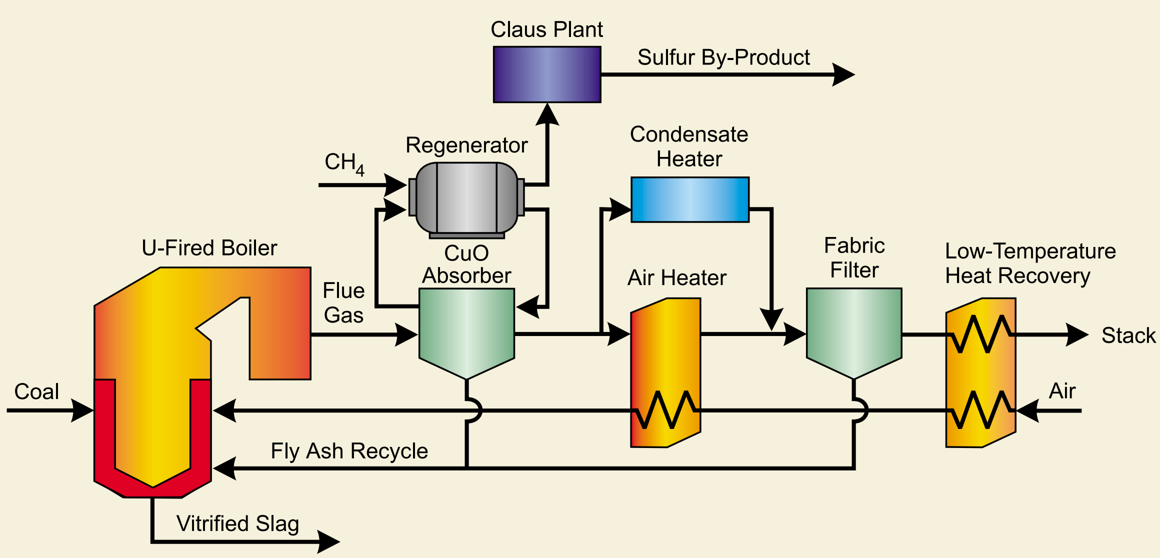
Three teams were competitively selected to participate on a cost-shared basis in the LEBS program. Three boiler manufacturers headed up technology teams, each with a "user" advisory panel comprised of utilities and non-utility generators. After engineering development and testing, the three industry teams submitted designs for a 400-MWe commercial plant along with proof-of-concept approaches. In September 1997, the DB Riley team was selected to construct and operate an 80-MWe LEBS unit in Elkhart, Illinois.

The DB Riley LEBS design features a novel U-fired furnace and moving-bed copper-oxide flue-gas cleanup system. The U-fired furnace converts nearly all of the coal ash into a glass-like slag. Particulate matter (PM) is controlled by a fabric filter. This glass-like slag represents about one-third the volume of fly ash and is a high-value product used as blasting grit and roofing granules. To further reduce or eliminate solid waste management problems, the copper-oxide moving-bed system employs a reusable alumina-based and copper-oxide coated sorbent for SO_2 and NO_x removal.

SO_2 is controlled by reacting with the copper-oxide on the alumina sorbent and oxygen to form copper sulfate. The sulfated sorbent is regenerated by introducing methane, which removes the sulfur as a concentrated stream of SO_2 easily converted to high-value sulfur products.

NO_x control starts in the U-fired furnace where combustion is staged by reburning — a process creating a fuel-rich zone above the main burners to strip oxygen from nitrogen compounds and completing combustion in an oxygen-rich zone at relatively low temperatures. Further NO_x reduction is achieved by injecting ammonia upstream of

Low-Emissions Boiler System



Advanced, low-NO_X, U-fired boiler produces environmentally benign inert slag

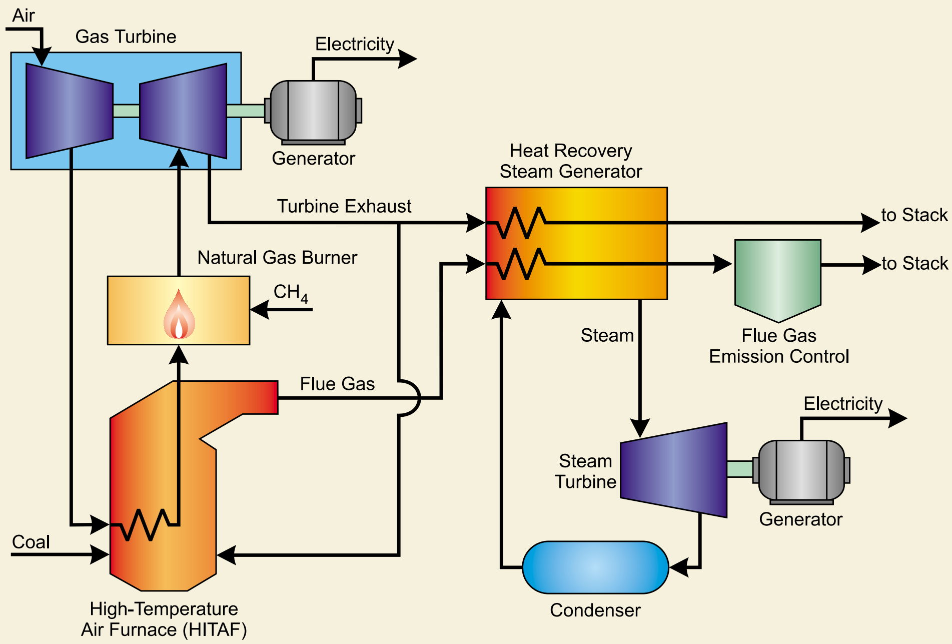
Copper-oxide flue-gas cleanup system removes 96%–99% of SO_2 and, if needed, 99% of NO_X

Heat recovery to air, condensate

Fabric filter for particulate collection

Air heater recovers heat from flue gases for increased efficiency

Indirect Fired Cycle



the sulfated sorbent, which serves as a catalyst to convert ammonia and NO_x into nitrogen and water.

LEBS is expected to exceed new source performance standards for pollutant emissions and to have efficiencies far beyond the 35 percent efficiency of 1st generation pulverized coal-fired systems. Plans are to initiate proof-of-concept testing in 2000 and realize market entry by 2003.

Indirect Fired Cycles

Performance Targets

Efficiency: 55% HHV

Emissions:

NO_x – 0.06 lb/10^6 Btu
SO_2 – 0.06 lb/10^6 Btu
PM – 0.003 lb/10^6 Btu

Year: 2010

Indirect Fired Cycle (IFC) is an indirectly fired gas turbine combined-cycle where the high-temperature corrosive gas from coal combustion does not contact the gas turbine. The heat is transferred to a clean working media —air— avoiding the need to clean coal combustion gases at high-temperature to achieve high-efficiency. Air under pressure from a gas turbine compressor is heated in a high-temperature air furnace (HITAF) and is expanded in the gas turbine. The option exists to add further energy to the air working media by combusting a clean fuel gas, such as natural gas or coal-derived fuel gas. Heat recovered from the gas turbine exhaust and HITAF flue gas is used to raise steam for a steam turbine.

The challenge to realizing the benefits of this indirectly fired cycle lies in the development of an effective high-temperature heat exchanger, the HITAF. Two competitively selected teams are presently addressing this challenge, led by Foster Wheeler Development Corporation and United Technologies Research Center. When fully developed, both versions of High-Performance Power Systems are expected to achieve efficiencies of 55 percent.

The teams are currently engaged in component and subsystem testing and refining system designs. Both IFC designs are capable of efficiencies of 55 percent. The teams are currently testing components and subsystems for consideration as Vision 21 modules.

Pressurized Fluidized-Bed Combustion

Performance Targets

Efficiency: 52% HHV

Emissions:

NO_x – 0.06 lb/10^6 Btu
SO_2 – 0.06 lb/10^6 Btu
PM – 0.003 lb/10^6 Btu

Cost: <$1,000/kW

Year: 2008

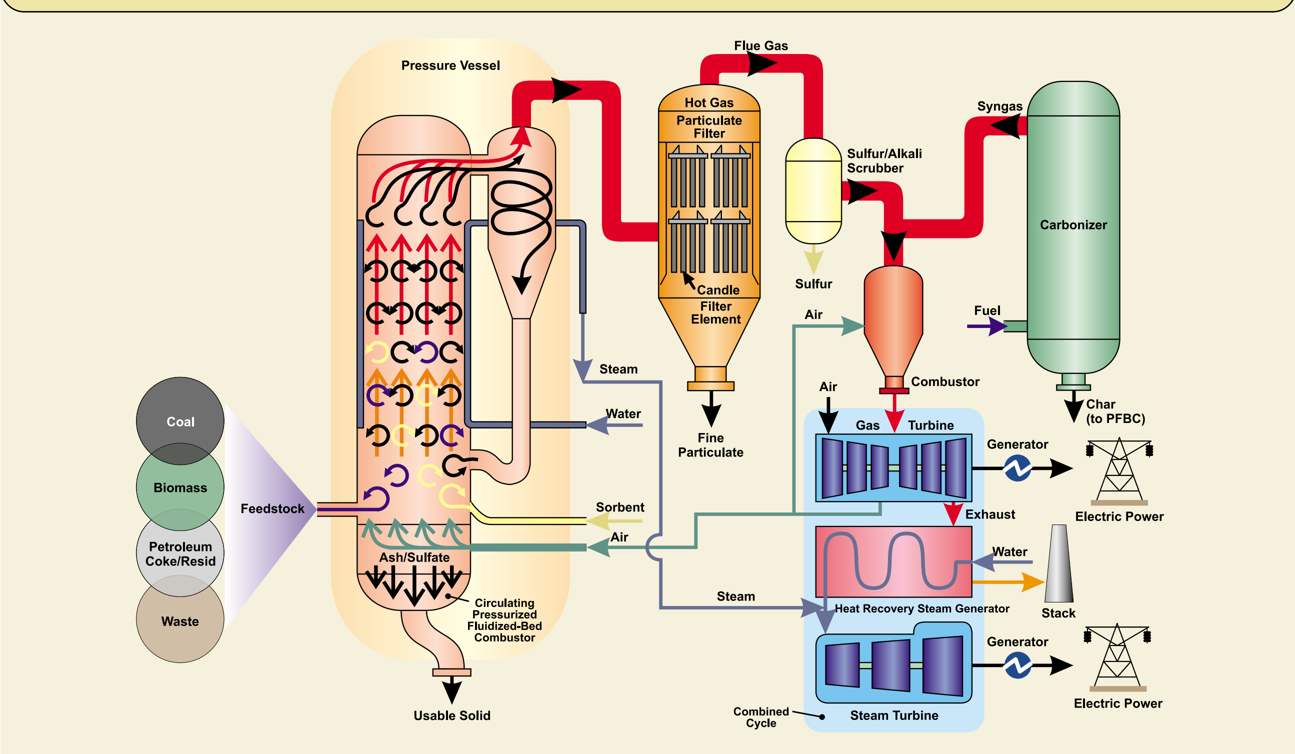
Fluidized beds use a gas such as air to entrain solids. The result is a turbulent tumbling and mixing of gas and solids acting much like a fluid, which is effective for chemical reactions and heat transfer. Fluidized-bed combustion (FBC) evolved from efforts to find a combustion process able to control pollutant emissions without external controls. FBC enables efficient combustion at temperatures of 1,400–1,700°F, well below the thermal NO_x formation temperature (2,500°F), and results in high SO_2 capture efficiency through effective sorbent/flue gas contact.

Pressurized fluidized-bed combustion (PFBC) builds on earlier work in atmospheric fluidized-bed combustion (AFBC) technology. AFBC is achieving significant market penetration, with most boiler manufacturers currently offering AFBCs as a standard package. This success is largely due to CCT Program efforts and the C&PS and industry partners' R&D leading to demonstration. The popularity is attributed to the tremendous fuel flexibility and SO_2 and NO_x emission control without the need for add-on controls.

The CCT Program has also resulted in market entry of 1st generation PFBC, with an estimated 1 gigawatt of capacity installed worldwide. These PFBC systems pressurize the fluidized bed to generate sufficient flue gas energy to drive a gas turbine and operate it in a combined-cycle. The 1st generation PFBC uses a "bubbling-bed" technology. A relatively stationary fluidized-bed is established in the boiler using low air velocities to fluidize the material, and a heat exchanger (boiler tube bundle) immersed in the bed to generate steam. Cyclone separators are used to remove particulate matter from the flue gas prior to entering a gas turbine, which is designed to accept a moderate amount of particulate matter (i.e., "ruggedized").

A 2nd generation PFBC, currently under development, uses "circulating fluidized-bed" technology and a number of efficiency enhancement measures. Circulating fluidized-bed technology has the potential to improve operational characteristics

2nd Generation Pressurized Fluidized-Bed Combustion



by using higher air flows to entrain and move the bed material, and recirculating nearly all the bed material with adjacent high-volume, hot cyclone separators. The relatively clean flue gas goes on to the heat exchanger. This approach theoretically simplifies feed design, extends the contact between sorbent and flue gas, reduces likelihood of heat exchanger tube erosion, and improves SO_2 capture and combustion efficiency.

A major efficiency enhancing measure for 2nd generation PFBC is the integration of a coal gasifier (carbonizer) to produce a fuel gas. This fuel gas is combusted in a topping combustor and adds to the PFBC flue gas energy entering the gas turbine, which is the more efficient portion of the combined cycle. The topping combustor must exhibit flame stability in combusting low-Btu gas and low-NO_x emission characteristics. To take maximum advantage of the increasingly efficient commercial gas turbines, the high-energy gas leaving the topping combustor must be nearly free of particulate matter and alkali/sulfur content. Also, releases to the environment from the PFBC system must be essentially free of mercury, a soon-to-be regulated hazardous air pollutant.

To reduce cost and CO_2 emissions, new sorbents are being evaluated. Sorbent utilization has a major influence on operating costs, and CO_2 emissions streams can result in the production and use of alkali-based sorbents.

Efforts are ongoing at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama to ensure critical components and subsystems are ready for demonstration of 2nd generation PFBC. The PSDF is operated by Southern Company Services under DOE contract to conduct cooperative R&D with industry. Plans are to demonstrate 2nd generation PFBC at Lakeland Electric's McIntosh Power Station in 2006.

The Power Systems Development Facility, located in Wilsonville, Alabama and operated by Southern Company Services, focuses on power system components and subsystems.

Tests conducted at the PSDF in 1998 verified that a newly developed multi-annular swirl burner (MASB) provided the needed flame stability and low-NO_x performance characteristics. Tests of promising new hot gas filter components and systems are continuing at the PSDF. Advances made to date in this critical technology area include the development of clay-bonded silicon carbide candle filters and the associated filter vessel. Efforts are currently focused on improved candle filter materials for enhanced durability under extreme temperatures and corrosive environment. New ceramics and ceramic-metallic composites are showing promise. Those passing laboratory screening tests will undergo testing at the PSDF.

Alkali and sulfur compounds have the potential to cause chemical corrosion of gas turbine blades at the temperatures sought for efficient operation. Data must be obtained to determine the maximum allowable limits and control systems must be developed to ensure that the limits are not exceeded. The PSDF will play a role in verifying that the appropriate controls are developed.

Moreover, the PSDF and NETL in-house facilities will be used: (1) to examine new sorbents that have the potential to more efficiently capture SO_2 and lessen or eliminate CO_2 emissions; and (2) to evaluate HAPs control measures to ensure compliance with anticipated standards.

To further enhance efficiency, 2nd generation PFBC will incorporate the gas turbines emerging from the ATS Program, and eventually will include a supercritical steam cycle. With all these features, 2nd generation PFBC is expected to achieve a 52 percent efficiency and have near-zero NO_x, SO_2, and particulate emissions. Market entry is projected for 2008.

Gasification Technologies

Performance Targets

Efficiency: >52% HHV

Emissions:

NO_x – 0.06 lb/10^6 Btu
SO_2 – 0.06 lb/10^6 Btu
PM – 0.003 lb/10^6 Btu

Cost: <$1,000/kW

Year: 2008

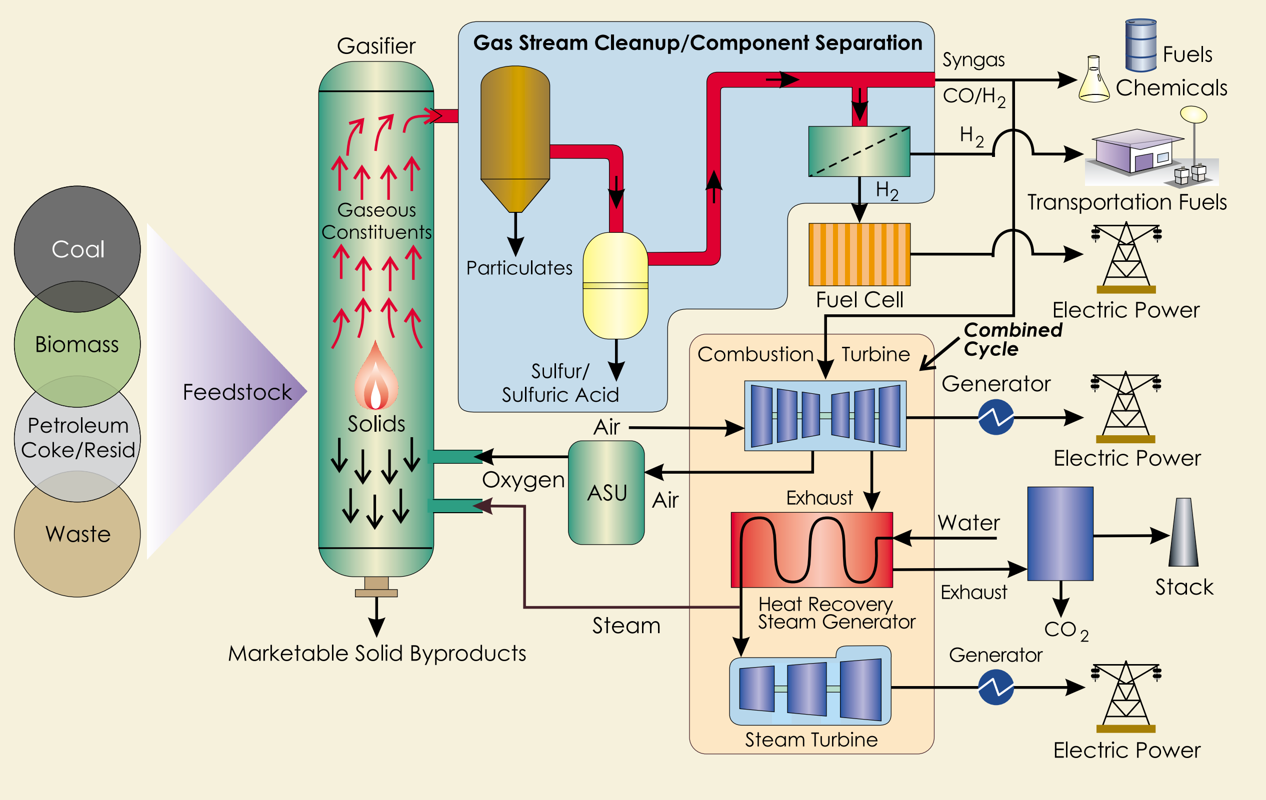
Gasification technologies represent the next generation of solid feedstock-based energy production systems. The heart of these systems is the gasifier. This unit is responsible for converting any carbon-based feedstock into synthesis gas, a mixture of carbon dioxide and hydrogen. This conversion is accomplished under high pressures and temperatures in the presence of steam and air/oxygen. Under these conditions, chemical bonds in the feedstock are broken and the constituents are further reacted to form synthesis gas.

The mineral matter in the feedstock separates from the gaseous products and leaves the bottom of the gasifier either as an inert glass-like slag or other marketable solid product. The synthesis gas from the gasifier, besides containing carbon monoxide and hydrogen, also has smaller quantities of hydrogen sulfide, methane, ammonia, and particulate matter. The synthesis gas is subsequently cleaned of these impurities to meet the requirements of downstream process units.

Once cleaned, the synthesis gas can be used, in whole or in part, to produced electricity, steam, fuels, chemicals, hydrogen, and substitute natural gas. Integrated Gasification Combined-Cycle (IGCC), one configuration of gasification-based processes, utilizes the clean synthesis gas to fuel a gas turbine. The gas turbine drives an electric generator and its exhaust gas is used to produce steam to drive a steam turbine/generator. IGCC is one of the most efficient and environmentally friendly of today's commercial and advanced power generation technologies, and can be further enhanced through integration with fuel cells.

Gasification-based processes are the only advanced technologies that offer both feedstock and product flexibility while simultaneously achieving near-zero emissions of sulfur and nitrogen oxides and particulates. High operating

Gasification-Based Systems Concepts



efficiency of future gasification technologies (>52%) reduces CO_2 emissions, and the processes are readily adaptable for concentrating the remaining CO_2 for sequestration, a Vision 21 requirement. Through the development of advanced technologies, capital costs are expected to be reduced to below $1,000/kW by 2008, making gasification competitive with natural gas combined-cycle and the technology of choice for solid feedstocks.

To meet energy market demands and facilitate global commercial acceptance of gasification-based technologies, the program strategy emphasizes increased efficiencies, cost reduction, high system reliability and availability, feedstock and product flexibility, and near-zero emissions of pollutants**.** The strategy consists of two key elements: Gasification Systems Technology and Systems Analysis/ Product Integration.

Wabash River Generating Station was repowered with a 262-MWe IGCC unit shown here

Gasification Systems Technology

R&D conducted by industry, academia, nonprofit institutions, and government laboratories focus on gasification, gas cleaning, gas separation, and product/by-product utilization. Research on ***advanced gasifiers*** such as the transport gasifier offers potential for achieving performance goals and increasing feedstock flexibility. Fluid dynamic data and advanced computational fluid dynamic modeling are being used to support the development of advanced gasifiers. The use of alternative feedstocks, such as biomass and refinery, industrial, and municipal wastes, is being explored to improve gasifier flexibility. Advanced refractory materials and process instrumentation are being developed to improve gasifier performance, operational control, and reliability.

To achieve near-zero emissions while simultaneously reducing capital and operating costs, novel ***gas cleaning and conditioning*** technologies are undergoing development. Such technologies are also needed to meet the gas quality requirements for fuel cell and synthesis gas conversion technologies. Technologies that operate at mild to high temperatures and incorporate multi-contaminant control are being explored. Successful technologies will undergo further development at NETL's Gas Processing Development Unit (GPDU) or at the PSDF.

Research into ***advanced gas separation*** technologies offers the key to expanded opportunities for gasification-based technologies through the elimination of conventional energy intensive processes. Novel membrane-based air separation technologies offer potential for substantial reductions in the cost of oxygen compared to today's cryogenic technologies while simultaneously enhancing process efficiency. New advances for the manufacture of hydrogen will make gasification an important technology in the transition to a hydrogen economy. Development of advanced membranes and CO_2 hydrate technologies will result in the separation of a pure hydrogen stream for fuel cell applications while simultaneously concentrating CO_2 for sequestration.

Finally, the economics of gasification-based processes can be improved by producing ***value-added products*** from waste streams and minimizing waste disposal. Technologies are being developed to improve the quality of the gasifier ash and slag, and to develop new market applications.

New approaches for recovering sulfur are also being explored to reduce processing costs.

Systems Analysis/Product Integration

Economic analyses, process performance assessments, and market studies will provide the necessary engineering and economic guidance for future R&D initiatives and will support domestic and international commercialization opportunities. Process optimization studies are being pursued to determine the lowest cost and highest efficiency approaches for baseload, cogeneration, and coproduction applications. Similar studies will also be pursued for advanced configurations that incorporate fuel cells and CO_2 capture technologies. Life cycle analyses are being performed to evaluate cradle to grave performance. Scoping studies to help define research needs and goals for all R&D projects is a continuing activity.

Technology integration and demonstration is an important component of the program to achieve market acceptance of the technologies. Under the CCT program, 1st generation IGCC technologies are being demonstrated at four separate facilities. Each project uses different gasifiers and gas cleanup systems. These processes largely employ conventional air separation, pollutant controls, and bottom cycles that are either energy intensive or sacrifice efficiency by operating at low temperatures. Next generation gasification technologies will seek to enhance performance by integrating thermally efficient particulate and sulfur control technologies, advanced turbine systems, new air separation technologies, and improved materials, instrumentation, and controls while incorporating lessons-learned from the CCT demonstration projects and optimization studies. Such systems are expected to have efficiencies in excess of 52% with near-zero emissions of SO_2, NO_x, and particulates.

The Gasification Technologies program is also embarking on projects that will lead to the demonstration of coproduction technologies for the manufacture of electricity, fuels, and chemicals and the application of gasification in the pulp and paper industry.

In FY 2000, a major new initiative focusing on the application of gasification to the pulp and paper industry is being implemented. Since the early 1970s, this industry has been looking for a safer, less expensive, and environmentally friendly alternative to conventional pulping liquor processing and wood residual combustion. Gasification has the potential for exceeding known and anticipated emission standards for SO_2 and NO_x, and achieving higher thermal efficiency, enhanced separation and regeneration of pulping chemicals, higher electric power generation, and improved safety. This new government/private sector initiative is focusing on the commercial demonstration of gasification-based technologies at existing U.S. mills. Successful demonstration of these technologies will provide the industry with the information needed to make informed decisions on replacing existing technologies with new technologies that are far superior in terms of environmental performance and efficiency.

The ***market potential*** for gasification-based processes is expected to grow considerably in the next few decades because of gasification's environmental performance and operational flexibility. Databases on existing and planned gasification-based projects have been developed and are continually being updated. This information will be used to develop market strategies for both domestic and international markets. To ensure that industry has the technologies to meet future market applications and environmental requirements, interviews will be conducted with industry to determine underlying needs. Based on these reviews and other ***outreach activities***, a technology roadmap will be developed jointly with industry.

Carbon dioxide emissions are captured and, along with flyash, are removed by barge for recycling or safe disposal.

Vision 21 Systems

Performance Targets

Efficiency:
Coal-powered – >60% HHV
Gas-powered – >75% LHV
Combined Heat/Power – 85-90% Thermal

Emissions:
Pollutants – zero
CO_2 – zero w/ sequestration

Cost: Electricity at market rates

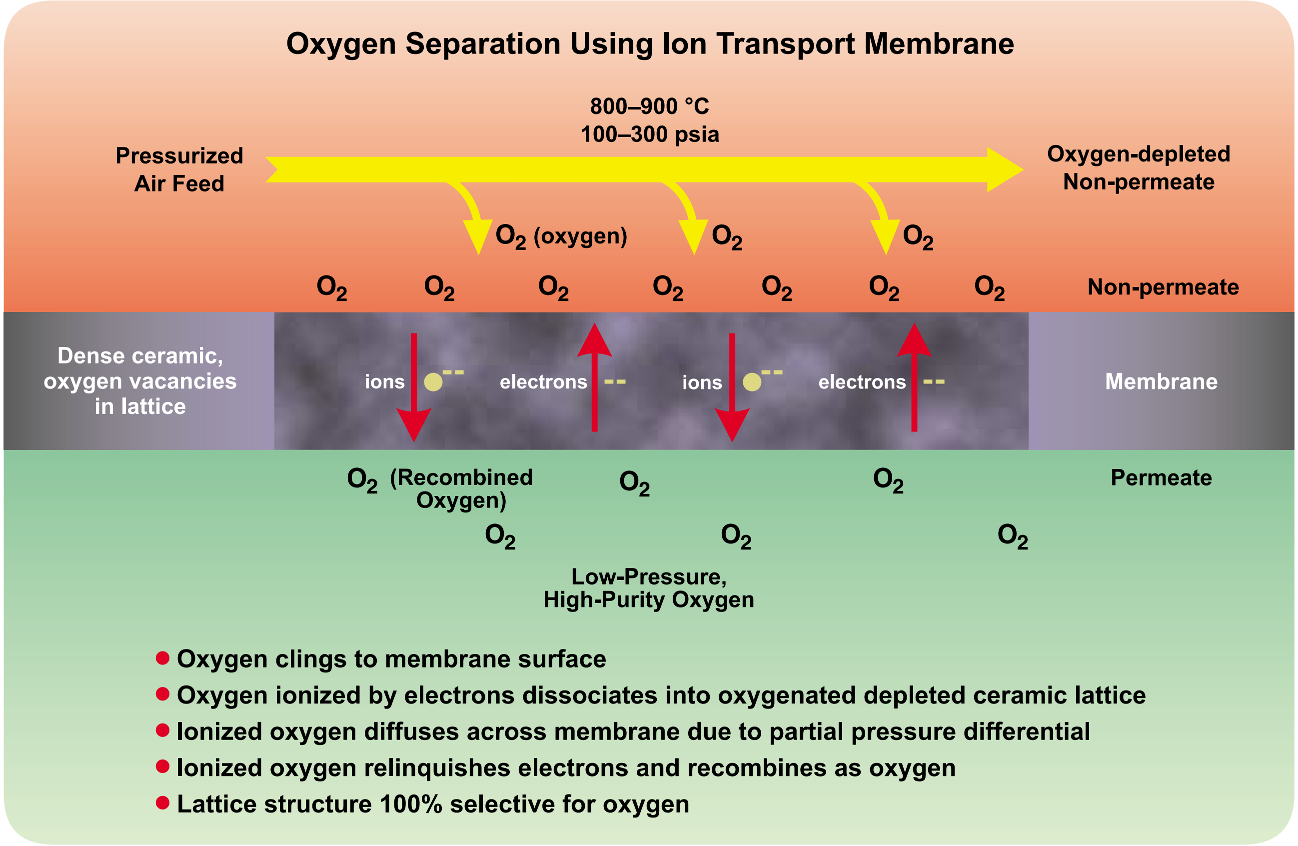
Year: 2015

Vision 21 is a government-industry-academia collaboration to develop technologies to effectively remove all environmental concerns associated with the use of fossil fuels. The approach is to develop a suite of technology modules that can be interconnected in different configurations to produce selected products. These modular facilities will be capable of using a multiplicity of fuels to competitively produce a number of commodities at efficiencies greater than 60 percent for coal-based systems and 75 percent for natural gas-based systems with near-zero emissions. Vision 21 builds on a portfolio of technologies already being developed, including PFBC, IGCC, HIPPS, advanced gas turbines, fuel cells, and fuels synthesis, and adds other critical technologies and system integration techniques. When coupled with CO_2 capture and recycling or sequestration, Vision 21 systems would achieve no net CO_2 emissions and no adverse environmental impacts.

Many of the Vision 21 activities complement and extend focused activities to achieve 2nd generation PFBC and IGCC. For example, hot gas particulate filtration, hot gas sulfur/alkali control, and air separation are critical elements to one or both. Vision 21 addresses gas separation and cleanup, but extends the development effort to: (1) increasingly efficient and cost-effective measures for particulate and sulfur/alkali control and air separation; and (2) measures dealing with a broader range of gases, such as hydrogen and CO_2.

Advanced gas separation and cleanup are critical to achieving hybrid systems, fuel and product flexibility, and carbon sequestration. Hybrids and fuel and product flexibility offer the potential for major improvements in cost and performance. And effective CO_2 capture is a prerequisite to carbon sequestration.

A hybrid system showing great promise is integration of gasification with a fuel cell (IGFC). Fuel



cells offer very high efficiencies, with emerging fuel cells having 60 percent efficiency. These emerging fuel cells also produce very high-temperature exhaust gases that can either be used directly in combined-cycle or used to drive a gas turbine. IGFC hybrids have the potential to achieve up to 60 percent efficiency and near-zero emissions. Moreover, the concentration of CO_2 lends itself to removal by separation or other capture means. Such systems require that the syngas derived from gasification be free of contaminates for use in the fuel cell, or that the hydrogen be separated from the syngas (hydrogen is the fuel element for the fuel cell).

Fuel flexibility enables the use of low-cost indigenous fuels, renewables, and waste materials. Use of renewables and wastes contributes to solving environmental problems as well as reducing operating costs. The challenge is in developing effective feed mechanisms for these alternative fuels, establishing effective operating parameters, and providing the means to achieve the operating parameters and to control any new pollutants that might be formed. For ATS gas turbines, and hybrids incorporating ATS/fuel cells, fuel flexibility requires research to address combustion of low-Btu gases and maintaining low-NO_x emissions at increasingly higher temperatures.

Product flexibility allows power suppliers to supplement revenues by designing plants to site- or region-specific markets for high-value by-products. Many chemical and fuel processes, however, require nearly contaminant-free syngas and warrant improvements to enhance product quality.

Carbon sequestration is the ultimate solution to stabilizing global carbon emissions. A prerequisite to carbon sequestration is carbon capture, which for power systems is CO_2 capture. Power system developments are moving toward higher efficiency to lower CO_2 emissions on a per-Btu basis and toward more concentrated CO_2 emission streams through oxygen- rather than air-based gasification and combustion. Air separation efforts support the move to oxygen-based systems. Ultimately, the CO_2 must be captured either through chemical or physical separation methods.

Vision 21 is addressing the challenges outlined above through a cooperative effort involving industry, universities, and National Laboratories. It includes fundamental research in materials science, novel concept evaluation at bench-scale, and process verification at pilot-scale. Facilities such as the GPDUnit at NETL and the PSDF at Wilsonville, Alabama, along with industry/National Laboratory/university facilities, are being enlisted to address these challenges.

Specific examples of Vision 21 activities include development of: (1) a dense ceramic ion transport membrane for air separation (ITM), (2) a transport reactor for fuel-flexible gasification and sulfur/alkali control, (3) a CO_2 hydrates system for CO_2 capture and hydrogen separation, (4) a ceramic proton-transfer membrane (PTM) for hydrogen separation, (5) an early-entry IGFC system, (6) an early-entry coproduction plant (EECP), and (7) a hybrid gas turbine fuel cell power module.

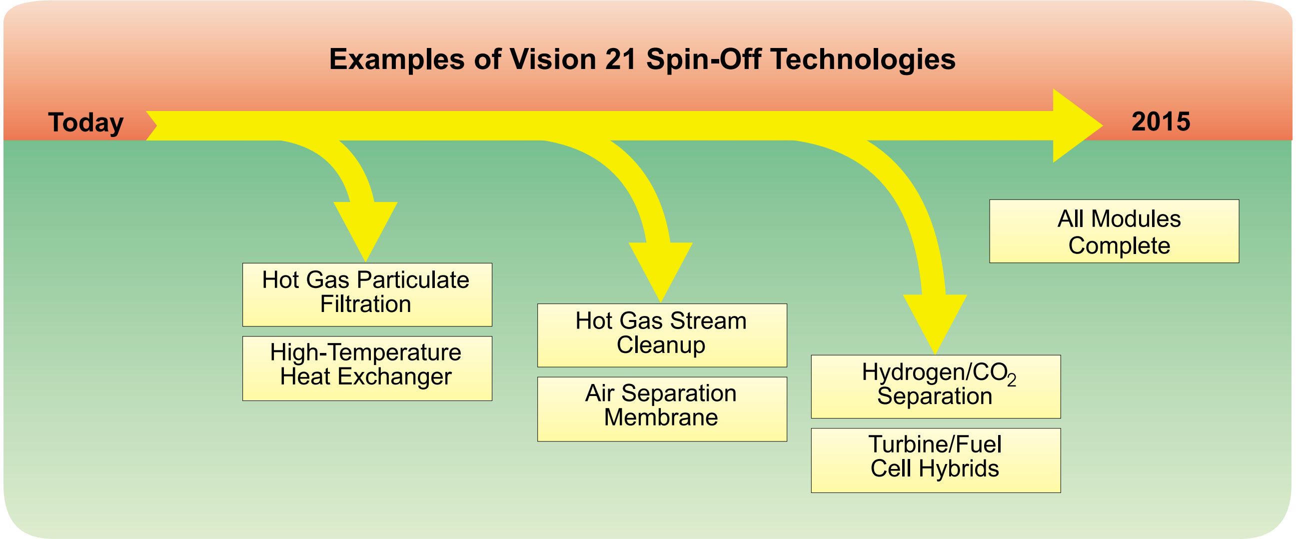
The ITM can reduce IGCC plant costs and opens the way for oxygen-rich advanced combustion systems. Air separation represents 15–25 percent of IGCC plant costs. Oxygen-rich combustion along with CO_2 recycle shows promise for efficient, low-NO_x combustion and concentration of the CO_2 in the flue gas, which facilitates capture.

The transport reactor used at the PSDF is a unique system capable of emulating both fluidized-bed combustion and gasification. This reactor also exhibits a high degree of fuel flexibility, and for that reason, is a subject of development efforts to fully evaluate its potential as a commercial gasifier. In addition, the reactor provides the platform for a hot gas cleanup system using regenerable sorbents for sulfur/alkali removal.

Integration of a CO_2 hydrates system with IGCC offers a low-temperature approach to chemical separation of hydrogen from the synthesis gas, and formation of a concentrated CO_2 stream. The PTM separates hydrogen from the hot synthesis gas using a ceramic membrane.

Early hybrid designs, such as IGFC and Early Entry Coproduction Plant, are examining integration issues related to incorporating gasifiers with fuel cells and fuel process technologies.

To accelerate market entry of Vision 21 systems, the implementation strategy includes having early entry spinoff technologies, which become commercial products over the 15 year span of the program. The spinoffs will realize early commercialization because they represent significant breakthroughs in cost and performance, such as the air separation membrane for low-cost oxygen production. Oxygen represents the third most marketed commodity in the United States. The first Vision 21 plants will integrate many of these advanced spinoff components, which will have already been demonstrated in different applications. This method reduces risk and is expected to take the place of government funded full scale Vision 21 plant demonstrations. Subscale integration tests, using both computational simulation and hardware, will be conducted to prove out the systems integration technology. Improvement of these virtual demonstration techniques will also be a part of the Vision 21 effort.



Program Successes

Tampa Electric Company

In 1989, Tampa Electric Company embarked on a mission to respond to customer needs for additional power in the most fiscally and environmentally responsible manner possible. Tampa Electric first engaged environmental groups to identify a plant location that represented the least threat to the environment. A consensus was reached on an abandoned phosphate mine site in Polk County, Florida. Coal was chosen as the fuel to keep operating costs low, and IGCC technology was selected to provide the least environmental impact.

Tampa Electric Company collaboration with environmental groups resulted in the creation of uplands, wet lands, and a wildlife corridor.

In 1996, the 250 MWe IGCC Polk Power Station, Unit No. 1 went on line and continues in commercial service. The heart of the unit is a Texaco oxygen blown, entrained flow gasifier. As of September 1999, the IGCC system had accumulated over 16,000 hours of operation and produced over 4,500,000 MWh of electricity.

The project has drawn visitors from around the world, and the Texaco gasifier-based IGCC is realizing a significant number of commercial sales.

For its accomplishments, the project is the recipient of "Power" magazine's 1997 Powerplant Award, the 1993 Ecological Society of America Corporate Award, the 1993 Timer Powers Conflict Resolution Award, and the 1991 Florida Audubon Society Corporate Award.

The 4,000-ton Model MS7001H (H System™) turbine is the size of a locomotive

Tampa Electric Company's 250-MWe Polk Power Station, Unit 1 IGCC Facility

General Electric's *H System*™ Turbine

In September 1999, General Electric (GE) announced that its newest H System™ gas turbine was ready to move over the commercial threshold. Having passed a critical verification test, the H System™ gas turbine will be sited at Sithe's Heritage Station in Scriba, New York. This turbine is a culminating achievement of the Department of Energy's Advanced Turbine System research and development program that began in the early 1990s, when GE was one of six developers selected to begin designing concepts for a breakthrough turbine system.

Designed to work in a combined-cycle mode, the H System™ gas turbine will be the first to break through the 60 percent efficiency threshold, beating the efficiency of prior best available turbines by five percentage points. This significant jump in efficiency makes the H System™ turbine the lowest producer of carbon dioxide per kilowatt of electricity of any gas turbine available today.

Moreover, the H System™ turbine operates cleaner than any of today's utility gas turbines. Its nitrogen oxide emission levels of 9 parts-per-million will be half the average of the turbines now in use, making the new technology suitable for siting in the nation's most environmentally constrained areas.